ADEK Award for Research Excellence (AARE-2018)
COVER SHEET

Title of Proposal	Care4MyHeart: Personalized management of Cardiovascular Diseases via technology-enabled behavioral change
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Primary Proposal Area (Only Check One Please)	Water [ ], Energy [ ], Environment [ ] Materials [ ], Infrastructure [ ] Aerospace [ ], Robotics [ ], Artificial Intelligence [ ] ICT [ ], Electronics [ ] **Health [x]**, Food and Agriculture [ ] Education [ ], Social Sciences [ ]
Secondary Proposal Area (Only Check One Please)	Water [ ], Energy [ ], Environment [ ] Materials [ ], Infrastructure [ ] Aerospace [ ], Robotics [ ], **Artificial Intelligence [x]** ICT [ ], Electronics [ ] Health [ ], Food and Agriculture [ ] Education [ ], Social Sciences [ ]
Proposal Keywords (Optional)	Cardiovascular disease (CVD); personalized cardiac rehabilitation management; machine learning; modeling techniques; behavioral change; advanced decision support systems.

Proposal Budget Summary	
Total Requested Funds	**299.539**
Total Cash Cost Share	0
Total In-kind Cost Share	1.022.863
Requested Funds in Year 1	184.193

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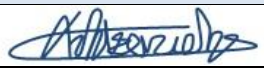
Signatures	
PI Signature	
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Executive Summary

Cardiovascular disease (CVD) is the major cause of death in the UAE, causing one in every five deaths. Effective Cardiac Rehabilitation (CR) can significantly improve mortality and morbidity rates, leading to longer independent living and a reduced use of healthcare resources. The proposed project, namely Care4MyHeart, sets as an overall goal to introduce a personalized home-based CR program, enabling lifestyle behavioral change towards increased quality of life, surpassing the currently unsustainable provision of healthcare for CVD. This multidisciplinary project aims to empower ordinary CVD patients to become 'expert patients', their own primary caregiver, with the know-how to self-manage their CVD. The proposed Care4MyHeart platform will help reduce patients' CVD risk, by gradually establishing a behavior change in their everyday living routine. It will utilize advanced machine learning and modeling techniques to provide gender- and age-specific CVD exercise programs and an autonomous helper-agent, providing informed feedback to the patient and the healthcare provider, establishing a collaborative patient-professional partnership. Overall outcome will be a 'co-production of health' business model from a multi-stakeholder eco-system, towards the integration of Care4MyHeart into healthcare systems across Arab countries and internationally. Care4MyHeart will be realized via motion capture, exercise evaluation, physiological and lifestyle monitoring, exercise gaming, home-based human-computer interfacing, multi-parametric data modelling and advanced decision support systems. The overall concept and system are easily transferable to address other diseases/conditions (e.g., diabetes, osteoporosis, obesity), providing market opportunities for the commercialization of Care4MyHeart beyond CVD, thus aligning with the major targets of the Abu Dhabi 2030 healthcare plan. Care4MyHeart will be realized in collaboration with the Cleveland Clinic AD and it is expected to establish KUST as an internationally recognized center of excellence in personalized healthcare, generate intellectual property, and expose graduate and undergraduate students to the state-of-the-art in signal processing-, biomedical engineering- and healthcare-related research.

Research Plan

Background & Motivation

Background: CVD collectively refers to diseases of the heart and circulatory system including coronary artery disease (CAD) and congenital heart disease (CHD). It is the leading cause of premature death (30% of all deaths) and disability worldwide (WHO) [1]. It is one of the leading causes of long term sickness and loss to the labor market with a huge economic cost (CVD global cost of US$863b, in EU economy almost EUR 196 billion a year [2]). With changing demographics and deteriorating lifestyle this situation will worsen considerably [1], which is neither economically or socially sustainable. In the UAE, 30% of deaths are due to CVD; a recent (2015) report by the Dubai Health Authority (DHA) shows that **CVD is one of the leading causes of death in the Emirates, causing one in every five deaths**, as **diabetes is a major risk factor for heart attacks** and more than 20% of UAE's population is diabetic. Effective **Cardiac Rehabilitation** (CR) can significantly improve mortality and morbidity rates, leading to longer independent living and a reduced use of health care resources. Despite the high burden of CVDs **in Arab countries, little is known about CR delivery** [3]. Key reasons for this include: severe lack of programs, travel time, scheduling issues, lack of peer mentoring, and low self-efficacy associated with poor exercise technique and perceived poor 'body image' (not wanting to exercise with large groups of 'strangers'). In fact, CR is "a secondary prevention program, with exercise as the cornerstone of a comprehensive intervention" (European Association for Cardiovascular Prevention & Rehabilitation), which includes an educational program on healthy lifestyle (dietary habits, smoking cessation, substance consumption and learning to manage stress). There are generally three phases of CR: Phase I: in-hospital education; Phase II: a very structured education that begins after leaving hospital with out-patient return visits 2-3 times/week for supervised exercise training and education sessions; and Phase III: it requires the patient to self-manage his/her rehabilitation.

Importance: CR results in a significant reduction in cardiovascular mortality of 26% (Odds Ratio 0.74, 95% Confidence Interval, 0.57-0.96) [5] and all-cause hospital readmission rates [2]. Increased exercise/physical activity (PA) alone reduces all-cause mortality by 24% and provides considerable protection from cardiovascular risk factors and co-morbidities, leading to longer independent living and a lower use of health care resources. Nevertheless, patient CR uptake and adherence are very low in Europe [6] and in Arab countries [3], especially for Phase III; therefore, approximately 11% of eligible patients begin a long-term Phase III community-based CR program, which is further diminished by low adherence rates [6].

Improvement: Care4MyHeart will target individuals entering Phase III, as this is where large numbers of patients, who would benefit significantly from exercise and CR, drop out. Current, traditional methods for home-based behavioral change interventions are limited by a 'one size fits all' phenomenon, i.e., everyone receives similar print or video-based information, failing to consider individuality. Without tailoring, interventions do not adapt to the evolving immediate, short or long-term needs of their patients and feedback on specific elements of information is not delivered at optimal times. Additionally, coordinated social interaction or peer support is difficult to provide [7]. Care4MyHeart will support the key predictors for attendance to CR Phase III programs [8], including high program availability, ease of access to program location, high social connectivity, peer support (when peers share similar problems or/and can become peer mentors), and high self-efficacy.

Effect to current clinical practice: Care4MyHeart will develop an end-to-end modular technology platform that will allow CVD patients to better self-manage their illness through a supportive, dynamic,

holistic, home-based CR program, which has increased uptake and long-term adherence to exercise as its core aim, transforming completely the way the CR is perceived so far. Care4MyHeart will allow CR use at any time in a comfortable and personal environment, providing clear benefits to all members of the health eco-system to move away from a healthcare provider-centric system to a co-production model, which empowers patients to self-manage their health; a home-based system facilitates this.

Aims and Objectives

The **overarching aim of Care4MyHeart is to introduce a radically novel approach to CR that will ensure a paradigm shift towards empowering patients to more effectively self-manage their CVD, set within a collaborative care context with health professionals.** It has the potential to deliver significant cost savings to the healthcare system, and direct more appropriate utilization of healthcare resources. This will be achieved via a patient-centric holistic approach that specifically addresses the above barriers.

To realize the aforementioned aim, Care4MyHeart has set the following concrete objectives:

1. **Develop Care4MyHeart to empower ordinary people to become 'expert patients', their own primary caregiver, with the know-how to self-manage their CVD**. Care4MyHeart, using modules on self-management education will augment traditional patient education by providing remote, direct monitoring, training and feedback to patients, enabling them to gain an understanding of their own health and its challenges and to develop confidence and action plans to accomplish new behaviors.
2. **Design Care4MyHeart to specifically reduce patients' CVD risk SCORE** [4] through: (1) enhancing their participation in daily physical activity; (2) monitoring and reducing their time spent sitting; (3) improved patient adherence to standard CVD prevention and treatment guidelines, including their medication regimen, the quality in their dietary behavior and stopping smoking (if a smoker).
3. **Develop gender and age specific CVD exercise programs (an 'Exerclass' and 'Exergame') and an autonomous agent**, manifested as a virtual coach, to deliver the exercise programs and associated behavioral change methodologies.
4. **Create an information-driven Care4MyHeart platform where Cloud-stored data,** analyzed via big data analytics machine learning (e.g., deep learning), **are transformed to knowledge** that can be used to develop a collaborative patient-professional partnership, a co-production of health, with the aim of optimizing the patient's quality of life.
5. **Develop a 'co-production of health' business model from a multi-stakeholder eco-system** (patient, healthcare professionals, public healthcare regulators, health data managers, insurers and assurers, and commercial entities) that will maximize the likelihood of integrating Care4MyHeart into healthcare systems across Arab countries and internationally.

Novelty of Care4MyHeart: Care4MyHeart will advance the state of the art across multiple fields of study that clearly align with Khalifa University mission, strategic goals, and research priorities along with the Abu Dhabi 2030 plan regarding the health sector policy. In particular:

1. Unlike the traditional m-Health and e-Health systems for providing exercise information and monitoring, Care4MyHeart **provides an exercise intervention and includes a sensing-intelligent analysis**. Beyond the potential for a system specifically targeting CVD rehabilitation the use of ExerGame

and ExerClass type systems as proposed by Care4MyHeart **in other diseases of inactivity** (e.g., diabetes (severe percentages in UAE), obesity, some form of cancers, osteoporosis) **or general health** would be very straightforward and relatively cheap.

2. High social connectivity is predictive of good health and wellbeing, decreased overall mortality, as well as reducing the incidence of CVD and its progression [9]. However, the generation of socially supportive environment for many technology platforms is associated with significant time, resources (training) and financial burden. **Care4MyHeart will become a viable, cost-effective dynamic, interactive, socially connected medium**. Its social connectivity module will encourage remote participants (of up to 4 people) to continue exercising together post-hospital discharge in a virtual space from the comfort of their own home, overcoming the challenge of social isolation found in traditional home-based interventions. Care4MyHeart will develop a peer mentor program, using a combination of group and dyad approaches [9]. In this way, **opportunities for problem-solving skill development will evolve as part of the Care4MyHeart program**, as patients discuss issues pertinent to living with CVD, not just treating the disease.
3. Care4MyHeart will provide to health care professionals with **extremely relevant, aggregated information (directly sensed and manually input) on their patient's health that they previously did not have access to, that will support their decision making**. This information will help to develop a collaborative patient-professional partnership, **a co-production of health** [10], with the aim of supporting patients to live the best possible quality of life with their chronic condition.
4. **In Care4MyHeart, exercise goes beyond the classic methods of treadmill or bicycle training**, where medical knowledge and guidelines coexist with a "steady" activity, as, by using deep learning [11] and fuzzy logic modeling [12], will: (i) automatically modify elements of the class/game to increase enjoyment and adherence based on the modelled relationship between exercise adherence, enjoyment, and sensed motion, physiological response and social interaction, (ii) use the Avatar coach (in a smart TV, tablet, PC, Virtual Reality headset) within the Exergame/Exerclass to encourage social interaction (based on system sensing of social interaction) and to encourage users to engage in physical activity outside of the home (which could be rewarded with extra 'life-points' in the next gaming session), and (iii) include a standardized exercise (stress-) test to be completed every month as part of an exercise class/game.
5. **Care4MyHeart will introduce a new exercise evaluation protocol** based on joints' position, orientation, velocity and 3D gesture flow, providing instantaneous local and global level indications/scores. These will be combined with signal processing algorithms (e.g., dynamic time warping [13]) for accurate movement comparison.
6. **Novel features**, such as facial features, head movements, body postures and gestures, will be used in Care4MyHeart to provide activity recognition, which will be extended to emotion and intensity recognition within an exercise environment, for **measuring affect and engagement** [15], [16].

Research Plan & Methodology

Methodological approach: Care4MyHeart will methodologically be deployed (follow Fig. 1, No 1-13) via a collaborative platform [16] that will contain an autonomous avatar as a virtual coach (e.g., on smart TV/PC/Tablet or Virtual Reality headset), supporting an exercise class ('Exerclass') and exercise-based game ('Exergame'), to be completed individually or by a small number of remote participants, who are at a similar stage of CR. In addition, the platform will support real-time analysis and positive feedback

on exercise technique, along with day-long monitoring of participants' physiological responses before, during and after exercise. Sensed biosignals, captured by a smartwatch/smartphone and stored in the Cloud (e.g., Microsoft Azure), will be combined with patient's supplied information on other lifestyle factors. In this way, all data will be accessible anytime-anywhere by the researchers and the related physicians for classification and evaluation purposes. The data archiving will follow the rigorous HIPAA (Health Insurance Portability & Accountability Act) compliance requirement [14] to ensure data privacy and security. This process will involve guest operational system (OS) and the virtual machines (VMs) in the Cloud, when necessary, for models' updating, retraining and enhancing their predictions/classifications.

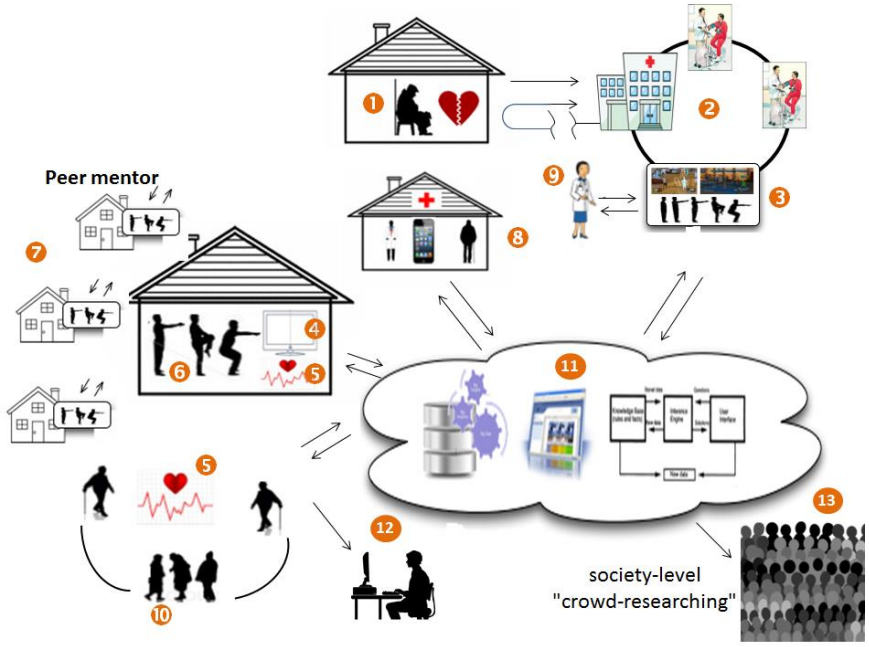

Fig. 1. Schematic representation of the proposed Care4MyHeart project with a sequence of interconnections (1-13).

Big data analysis and behavioral modeling: Both the sensed and user-provided data will be continuously aggregated and analyzed via big data analytics machine learning (using deep learning [11] and fuzzy logic modeling [12]) and used as the basis for analysis to adapt and personalize the patient's rehabilitation program over time, with abstracted summaries provided as feedback to both the patient and his/her clinician. The structure of human behavior deep learning modeling includes three layers (see Fig. 2): visible layer $\mathbf{v}$, hidden layer $\mathbf{h}$, and historical layer $\mathcal{H}$ [17]. In this deep learning model, self-motivation, implicit and explicit social influences, and environmental events are naturally incorporated together, so not only to accurately predict human behaviors, but also, for each predicted behavior, to generate explanations. In a graphical representation (see Fig. 2), given a user, each visible variable v_i in the visible layer $\mathbf{v}$ corresponds to an individual feature f_i at time t. All the visible variables of all the users in the previous N time intervals $\{t-N, \dots, t-1\}$ are included in a *historical layer*, denoted by $\mathcal{H}_{t<}$. In addition, the variables in the historical layer are called *historical variables*. Obviously, we will have $|\mathcal{F}| \times |U| \times N$ (see Fig. 2) historical variables. The hidden layer $\mathbf{h}$ consists of $|\mathbf{h}|$hidden variables. The process includes connection of the three layers together and modeling of the variables, in order to capture human behavior determinants and provide explanations for the predicted behaviors [17].

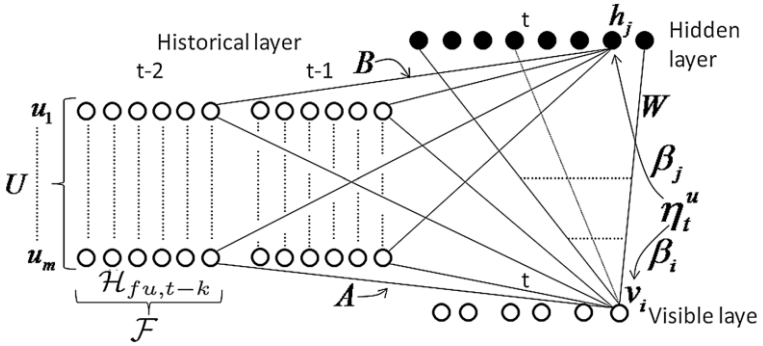

Fig. 2. The structure of the adopted human behavior modeling [17].

Patients and sample size: The sample size for Care4MyHeart is based on the assumption of a mean 10% higher increase (SD 25%) in energy expenditure (METs) in the intervention group compared to the control group during a 6-month period [18]. For this effect size with a power of 0.90 at alpha 0.05 (two-sided), a sample size of 22 participants is required (per treatment group) for the intention-to-treat (ITT) analysis. An estimated drop-out rate of 25% would require minimum 30 participants per group. We aim to recruit cost-wise 60 CVD participants, randomly assigned to participate in groups with intervention (30) and without (30), accordingly. Men and women between the age of 40-80 years with documented CVD, eligible for cardiac rehabilitation and have access to the Internet at home will be targeted, whereas individuals with untreated ventricular tachycardia, life threatening co-existing disease with life expectancy < 1 year, significant exercise limitations other than CVD, and intellectual disability that may compromise their ability to use a computer will be excluded from participating in Care4MyHeart.

Experimental Protocol: Participants in both groups will make a single visit to the Cleveland Clinic rehabilitation laboratory at baseline repeated at 3 and 6 months. During each visit, fasting 5ml blood sample (for total cholesterol, LDL and HDL, triglycerides, C-reactive protein), DEXA scan, blood pressure and a VO_2max with a 12 lead ECG (focusing at ST segment depression/elevation, Q-T morphology) will be measured. In addition, a blood sample will be taken and the Care4MyHeart questionnaire will be completed. The experimental group will participate in ≥ 30 min of moderate to vigorous aerobic-based exercise (MVPA) ≥ 5 days each week. Exercise will be self-regulated and will be monitored through the combination of sensor monitoring and participant responses to questions asked by the Care4MyHeart Avatar. Participants will self-report a rating of perceived exertion (Borg 20-point category scale) following each exercise session. Daily heart rate and physical activity/inactivity levels will also be monitored via a smartwatch and Kinect 2 sensors. A unique hardware/software home exercise system will be used to allow exercise to be performed in small social groups of remote participants. A 4-week hospital familiarization phase will embed the Care4MyHeart platform as a normal station within Cleveland Clinic CR in Phase II program. During the intervention period, there will be no direct human contact between the study participants and the research team. However, the participant's data will be remotely monitored by the research team and the Care4MyHeart Avatar will be designed to remind the participant to engage with Care4MyHeart via their mobile phone or via the Care4MyHeart system. No contact will be made with the control group. To the latter, a lifestyle advice relating to daily physical activity, smoking cessation, moderate substance consumption and healthy eating will be provided [19]. The home-based lifestyle intervention study will be submitted for ethical approval by the research ethics committee of Cleveland Clinic and all ethical principles for medical research involving human subjects will be followed (Declaration of Helsinki (2008), Directive 2004/23/EC), along with data security and privacy (Directive 95/46/EC, Directive 2002/58/EC). A written consent to participate will be asked in an entirely voluntary manner and will be

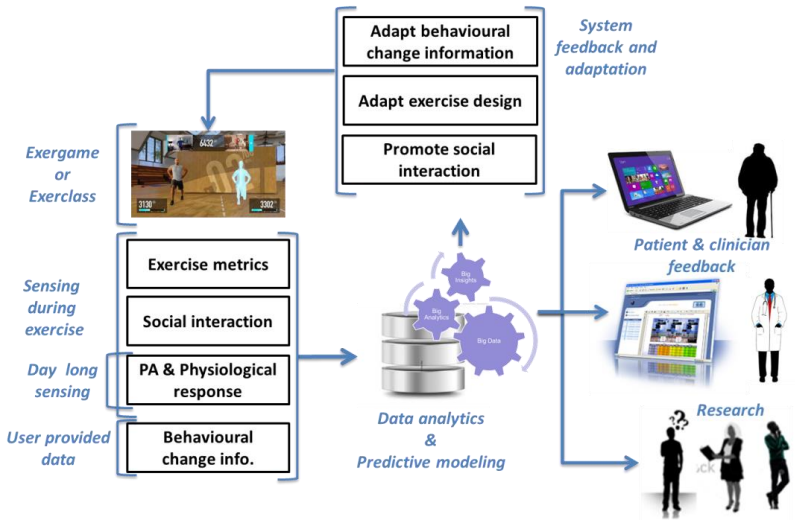

Fig. 3. Information and data in the Care4MyHeart platform.

signed by the participants based on full disclosure of information. An epitomized description of the information and data flow within Care4MyHeart is depicted in Fig. 3.

Work plan: Care4MyHeart will follow an iterative development cycle planned to allow close engagement between technical (KUST) and clinical (Cleveland Clinic) researchers involving educational enhancement of local Emirati students at KUST; it will support agile development methodologies with continuous updates into design/development, structured in the following breakdown (WP: Work packages, T: Tasks, D: Deliverables, MS: Milestones (MS), M: months duration, SM: Sami Muhaidat, KK: Kinda Khalaf, PS: Paschalis Sofotasios, FH: Faisal Hassan, ST: Local Emirati MSc/Undergraduate Students):

WP1	**Project management and coordination**	Start	M1	End	M24
Objectives: To coordinate communications between all members of research group; to address project objectives, meeting contractual obligations and deadlines; and to ensure goal setting, progress tracking, document management and effective information exchange. **{Collaborators involved}-Justification**: {PI, Co-PI, SM, KK}-PI has extensive experience in project management handling projects with funding of AED 15M in Europe. Co-PI has also much of experience in handling funding in UAE and from ADEC. SM has experience in data management, whereas KK, as BME Department Associate Chair, successfully deals with quality and technical progress monitoring.					
T1.1	Research group management {PI}	Start	M1	End	M24
T1.2	Data management {Co-PI, SM}	Start	M1	End	M24
T1.3	Technical progress monitoring and quality control {PI, TM}	Start	M1	End	M24
T1.4	Financial management and reporting {PI, Co-PI}	Start	M1	End	M24
D1.1, D1.2, D1.3, D1.4	Progress, Technical and Financial Official Reports (first, second, third, final progress reports)	Due	M6, M12, M18, M24		

WP2	**Requirements, user needs analysis and exercise program design**	Start	M1	End	M10
Objectives: To gather the clinical, regulatory, technical and functional requirements of the Care4MyHeart system involving all identified stakeholders; and performing a comprehensive needs identification and analysis. **{Collaborators involved}-Justification**: {Co-PI, KK, FH, ST}-Co-PI, KK and FH will combine their expertise in clinical cases/user requirements for the core of the Care4MyHeart Architecture; ST will assist in questionnaires construction/analysis and guided interviews with users.					
T2.1	Clinical requirements gathering {FH, ST}	Start	M1	End	M3
T2.2	Use-case and functional specification {FH, ST}	Start	M1	End	M10
T2.3	Co-design Care4MyHeart content for CVD population {Co-PI, TM, FH}	Start	M4	End	M10
D2.1	Clinical use-cases and function requirements definition report {Co-PI, ST}	Due	M3		
D2.2	Care4MyHeart content definition {Co-PI, TM, FH}	Due	M3, M10 (upd)		

WP3	**Patient and home exercise monitoring and interaction components**	Start	M2	End	M12
Objectives: To conduct the associated research and develop the technological components of the Care4MyHeart system, enabling the monitoring of the patient in order to adapt and personalize his/her rehabilitation program, through an engaging multi-party ExerClass and ExerGame. **{Collaborators involved}-Justification**: {All}-PI, Co-PI, KK, SM, PS and ST will take care of the technical characteristics of the exercise monitoring and interaction components, under the guidance of FH.					
T3.1	Motion capturing and exercise evaluation components {PI, Co-PI, FH, ST}	Start	M2	End	M12
T3.2	Physiological and physical activity monitoring {Co-PI, FH, ST}	Start	M2	End	M12

T3.3	Life-style information, social interaction and affective response components {FH, ST}	Start	M2	End	M12
T3.4	Patient multi-parametric modeling and decision support {SM, PS, ST}	Start	M2	End	M12
T3.5	Exergaming, virtual avatar and interfaces {PI, Co-PI, TM, ST}	Start	M2	End	M12
D3.1	Motion capturing and exercise evaluation module	Due	M12		
D3.2	Physiological sensor, life-style, social and affect modules	Due	M12		
D3.3	User modeling module	Due	M12		
D3.4	ExerGaming/Class and interface module	Due	M12		

WP4	**Care4MyHeart platform specification, implementation and validation**	Start	M2	End	M16
Objectives: To design a components' functional architecture; link together all technological modules developed in WP3 in a fully integrated system providing end user interfaces to both patients and clinicians; assess and provide feedback for WP3 ongoing development effort through validation tests based on use cases and scenarios identified in T2.2. **{Collaborators involved}-Justification**: {All}-PI, Co-PI, SM, PS and ST will provide the specifications and the implementation of the Care4MyHeart platform, whereas, all will validate the system functionality.					
T4.1	Care4MyHeart architecture and data model specification {PI, Co-PI, SM, PS, ST}	Start	M2	End	M7
T4.2	Implementation of Care4MyHeart platform {Co-PI, ST}	Start	M3	End	M12
T4.3	System Validation {All}	Start	M6	End	M16
D4.1	Care4MyHeart Unified Data Model and system architecture specification	Due	M4, M7 (upd)		
D4.2	Care4MyHeart first system prototype	Due	M8		
D4.3	Care4MyHeart full system prototype	Due	M12		
D4.4	Care4MyHeart platform validation test descriptions and system usability report	Due	M6, M12 (upd)		

WP5	**Evaluation of Care4MyHeart**	Start	M10	End	M24
Objectives: To examine the effect of Care4MyHeart on patient health status, adherence to standard CVD prevention/treatment guidelines, and service provision; analyze the societal and economic impact of the Care4MyHeart; and to understand the Care4MyHeart end-user's experience. **{Collaborators involved}-Justification**: {All}-PI, Co-PI, KK, SM, PS, and FH will evaluate Care4MyHeart both form technical and user functionality. KK and ST will perform a socioeconomic analysis whereas Co-PI and ST will perform intervention debriefs for capturing users' perspective.					
T5.1	Care4MyHeart Evaluation {PI, Co-PI, TM, SM, PS, FH}	Start	M13	End	M24
T5.2	Analysis of the Economic, Health and Social Impact of Care4MyHeart {TM, ST}	Start	M10	End	M24
T5.3	Care4MyHeart post intervention debrief {Co-PI, ST}	Start	M16	End	M24
D5.1	Evaluation results of Care4MyHeart	Due	M24		
D5.2	Report on economic, health and social impact of Care4MyHeart	Due	M24		
D5.3	Assessment of the Care4MyHeart experience of users	Due	M24		

WP6	**Dissemination, exploitation and commercialization**	Start	M1	End	M24
Objectives: To ensure the provision of the required environment and resources for the best possible dissemination and exploitation of the Care4MyHeart results; and to deliver the project results to its target groups-academics, public, health delivery/regulatory authorities, industry-related entities, as					

well as the end-users. **{Collaborators involved}-Justification**: {All}-PI and KK will focus in market watch and exploitation planning, whereas Co-PI, FH and ST will see the exploitation capabilities, so the ST could better be connected with the market opportunities, and KK with FH will see the impact in the healthcare system and the exploitable opportunities in Cleveland Clinic and beyond. All will contribute to the dissemination efforts, according to their network connections.					
T6.1	Market watch and exploitation planning {PI, TM}	Start	M1	End	M24
T6.2	Exploitation {Co-PI, FH, ST}	Start	M1	End	M24
T6.3	Dissemination and public outreach {All}	Start	M1	End	M24
T6.4	Health care system exploitation and impact creation {TM, FH}	Start	M1	End	M24
D6.1	Market, competitor and technology watch reports	Due	M6, M12 (upd1), M18 (upd2)		
D6.2	Online communication through project webpage	Due	M1		
D6.3	Publicity and communication media	Due	M6, M10 (upd)		
D6.4	Care4MyHeart dissemination and exploitation plans	Due	M6, M12 (upd)		
D6.5	Academic publications (e.g., in journals, conferences)	Due	M8, M12, M18, M24		
D6.6	Final report on networking and liaison actions	Due	M24		

Measures of success: To measure the success of the Care4MyHeart performance, some Key Performance Indices (KPIs) along with the corresponding Means to Measure (MtM) will be are adopted, i.e.: **KPI1**: Impact on physical and mental wellbeing {MtM: Tests at 0, 3 and 6 months (T5.1)}; **KPI2**: Improved communication with health professionals {MtM: Questionnaires at 0, 3 and 6 months (T5.1)}; **KPI3**: Effect on health outcomes & quality of life {MtM: Tests at baseline, 3 and 6 months (T5.1)}; **KPI4**: Effect on care efficiency gains & economic benefits {MtM: Health economic assessment (T5.2)}; **KPI5**: Provision of valid and reliable data on health outcomes (e.g, levels of PA, cardiac health) and their underlying determinants (e.g., metrics on exercise, social interaction, behavioural change, number of cigarettes smoked, a patient's level of fatigue) {MtM: Automatically and directly sensed via Care4MyHeart system, and input by patient via Avatar/key board (T4.4)}; **KPI6**: Health professional's opinion on the usefulness of the Care4MyHeart data in improving decision making {MtM: Needs analysis (T2.1,2.2); post intervention debriefs (T5.3)}; **KPI7**: Patient's level of satisfaction and trust in the 'Avatar's' advice based on the patient-led programme adjustments and using the summary feedback derived from sensors {MtM: Needs analysis (T2.1,2.2); 3 and 6-month questionnaires (T5.1); intervention debriefs (T5.3)}; **KPI8**: Community of learning, sharing of resources and information between patients, professionals and Care4MyHeart experts {MtM: 3 and 6-month questionnaires (T5.1)}; **KPI9**: Quantification of exercise adherence and activity {MtM: Evaluation based on system usage logs, along with activity (T5.1), normalised to personal schedule}; **KPI10**: Exercise adherence related to its determinants and reflected in health outcomes {MtM: In T3.4, based on analysis of all the factors recorded in T3.1-T3.3; intra-patient and inter-patient analysis will take place}; **KPI11**: Formation of distinct patient-related patterns {MtM: With availability of data, multi-dimensional clustering should be effective (T5.1)}; **KPI12**: Ability to extend model of exercise and its relations with daily life determinants, to include clinical, environmental and context factors {MtM: Standardisation of terminology. Review of concepts and semantics by experts. Tests for interoperability with external sources (T4.4, T5.3)}; **KPI13**: Health economic evaluation of Care4MyHeart {MtM: Economic report (T5.2)}; **KPI14**: End-users and stakeholders experience of Care4MyHeart {MtM: End users' evaluation (T5.3)}; **KPI15**: Creation and evaluation of a health ecosystem to design and implement Care4MyHeart {MtM: Needs analysis (T2.1); post-intervention debriefs of all stakeholders (T5.3)}; **KPI16**: Evidence of adoption/willingness to adopt Care4MyHeart by all stakeholders {MtM: Post-intervention debriefs of all stakeholders (T5.3)}.

Impact Statement

University: The project will contribute substantially to the academic activity in Khalifa University of Science and Technology (KUST), as MSc/Undergraduate students will collaborate with the PI and the co-PI towards nurturing the research and educational experiences of our students. Moreover, some undergraduate students will be involved through independent studies or senior design teams that will be involved with the intervention phase, assisting the CVD patients and helping in data collection protocols. Ties between KUST and Cleveland Clinic will be further leveraged, in order to secure technology transfer in patients' management, medical education and clinical practice.

Society: With populations that are increasingly older, more sedentary, with more unhealthy lifestyles, combined with growing costs of healthcare and less finances; healthcare service commissioners, employers, insurance and assurance providers are eager to explore new cost-effective and cost-efficient solutions. Care4MyHeart will be attractive because it reduces the time required by healthcare professionals to directly manage patient interaction and health, increases the health outcomes of the CR program and provides inbuilt monitoring systems to identify more (cost-) effective and personalized interventions. In addition, it can potentially return patients to work earlier.

Field: Care4MyHeart is an important research and innovation contributor, providing the basis for significant opportunities to demonstrate the creation of new personalized behavioral health interventions fit for global scale up, to facilitate adoption within healthcare systems, to strengthen the research of our academic community, and most importantly, to benefit society and our citizens through improved health. A significant benefit of Care4MyHeart in this regard is the direct (sensed) capture of large amounts of important data (exercise, physical activity, social interaction and behavioral change information access; physiological response).

Potentials for transferring research results to commercial values and IP management: The demand for migration from a highly constrained and regulated structure provides Care4MyHeart with significant and tangible opportunities for commercialization. The Care4MyHeart Cloud-based platform, the behavioral models, the motion capture, analysis and evaluation tools provide new generated IP. IP management will be considered and addressed within a dedicated IP Agreement (IPA), drafted and agreed as part of the Collaborators Agreement prior to the commencement research, in line with the KUST legal administration and Technology Transfer policies. IPA will respect the pre-existing know-how of the collaborators (background, mainly in data analysis) and also steer on post-project commercialization. An ancillary Exploitation Committee (chaired by the PI) will be formed, to co-ordinate IP-related issues and pursue dissemination and commercialization, especially via the Abu Dhabi's Technology Development Company (TDC) and its partner Mubadala, an R&D technology investment company.

Dissemination activities: Care4MyHeart will inform Abu Dhabi 2030 healthcare plan initiatives, such as Weqaya (a population screening and intervention program for Emiratis implemented by HAAD that focuses on diabetes and cardiovascular disease), and UAE organizations, such as Mubadala Healthcare, activated in the areas of personalized medicine, preventative medicine and health awareness, lifestyle adjustment, and treatment, via targeted presentations/workshops. Apart from the social media exposure (e.g., www.Care4MyHeart.net, Facebook, Tweeter) for worldwide visibility, demonstrations at hospitals (e.g., Cleveland Clinic, Burjeel, Healthpoint), and to related Societies (e.g., Emirates Cardiac Society, European Society of Cardiology, Canadian Cardiovascular Society, British Cardiovascular Society) will be carried out, helping to ensure penetration into healthcare system and cardiologists' network, both within UAE and worldwide, supported by research papers to their connected conferences and journals.

Award Management Plan

Team management: The project builds upon a multidisciplinary team of highly research-active researchers with ongoing collaboration (e.g., [20]-[22]) and expertise in all three relevant disciplines: signal processing [23]-[25] and biomedical engineering [26]-[31] (PI Dr Hadjileontiadis, Co-PI Dr Khandoker, Dr Khalaf), multivariate big data analysis and behavioral modeling (Dr Muhaidat and Dr Sofotasios) and cardiologist (Dr Hasan). Given the budget approved by ADEC, the project aims to recruit a research nurse on casual basis in the Cleveland Clinic, one MSc in Engineering student (local Emirati) and 10 undergraduate Biomedical/Electrical Engineering students at KUST. Detailed WP/Task-Collaborator correspondence is already provided in WPs description. From a high-level overview: **PI Dr Hadjileontiadis** will contribute total 10% of his time, taking principle responsibility for the entire project. He will supervise the graduate and undergraduate students and communicate all research outcomes, i.e., write research papers and present the results at conferences in collaboration with the other Investigators and his Greek Postdoc colleagues. **Co-PI Dr Khandoker** will contribute total 5% of his time, primarily being responsible for the motion data processing part, platform validation and co-supervision of the students with PI Dr Hadjileontiadis. **Dr Khalaf** will contribute total 5% of her time, primarily focusing in Care4MyHeart data quality monitoring and socioeconomic/healthcare impact. **Dr Muhaidat** and **Dr Sofotasios** will contribute total 5% of their time each, primarily focusing in system architecture, deep learning modeling and big data analysis. **Dr Hasan**, as a clinical Investigator, will contribute 5% of his time, primarily being responsible for selecting and recruiting the study participants, collecting clinical data in all subjects during experimental conditions and clinical interpretation of the findings. He will co-supervise undergraduate students involved in data collection in the hospital.

PI Dr Hadjileontiadis and his team at KUST, will be also responsible for training clinical staff in Cleveland Clinic to the use of the Care4MyHeart platform. His team will also participate in initial patient recruitment and gathering the data at Cleveland Clinic, to ensure the accuracy of data collection, integrity and finalization of staff training. At least one meeting in Cleveland Clinic in Abu Dhabi per month has been dedicated for updating and training of its staff. In October 2019, a workshop is planned in order to share progress locally with wider under/graduate student body, faculty and cardiologist under the Annual Emirates Cardiac Society congress in Abu Dhabi. One of the key deliverable of the project will be scholarly publications and therefore the focus of team meetings at the latter stage of the project will be the Journal of the American College of Cardiology (JACC) and presentations in International conferences (e.g., Royal College of Physicians (RCP), IEEE EMBEC).

Student's engagement: Thesis of the MSc Eng student to be recruited in the project will be based on WP2 and WP3 combining both system design and data analysis and modeling. Undergraduate ECE/BME students will be trained on how to treat with human subject for experiments with informed consent, how to follow an experimental protocol and how to collect the Care4MyHeart platform data and other clinical information in a confidential manner. Both PIs (Dr Hadjileontiadis from ECE and Dr Khandoker from BME) will supervise students' research training and Theses. It is anticipated that the student will be recruited from Abu Dhabi's national student body, as KUST has more than 1000 students enrolled of which over 75% are UAE nationals. During the project, they will also have an opportunity to expand their expertise in the area of data capturing and analysis by modern research methodologies.

Risk assessment: The spiral approach of Care4MyHeart implementation ensures that potential risks will be identified within the first implementation cycle, and will be appropriately addressed within the second cycle. Some potential risks (PR) with probability/impact/WP (P/I/WP) and mitigation actions (MA) refer to: **PR1**: Incompatible or in-correct equipment for Care4MyHeart platform components

{(LOW/HI/WP3, WP5), MA: Corrective actions, if necessary, are foreseen after the first usability testing}; **PR2**: The Care4MyHeart platform does not fulfil end user requirements and expectations {(LOW/HI/WP2, WP3, WP4), MA: A "richer" user acceptance test plan will be defined and implemented}; **PR3**: Failure to deliver an integrated accessible platform {(LOW/HI/WP4), MA: An appropriate maintenance operation to constantly refine the prototype will take place if necessary}.

Assessment of progress and success/Milestones: A regular collaborators' progress reporting process will be established (e.g., via the Web-based Teamwork tool), along with review rounds, to ensure maximum quality; success will be validated via Key-Milestones (MS#.#) (see Fig. 4 for time allocation). The MSs and their Means-of-Verification (MoV) include: **MS1.1/MS1.2/MS1.3/MS1.4**: Completion of ADEC project reporting requirements prior report submission {MoV: Submission of required reporting documents to the ADEC}; **MS2.1**: End of patient and stakeholder requirements gathering {MoV: Completion of interviews and D2.1}; **MS2.2**: Finalization of use-cases and functional specification {MoV: Completion and consortium acceptance of D2.2}; **MS2.3**: Completion of Care4MyHeart intervention content {MoV: Content definition documents made}; **MS3.1/MS3.2**: Patient and home exercise monitoring and interaction components ready for first (MS3.1) and final (MS3.2) prototype integration {common MoV: Components are functional and "up and running" on local test environment}; **MS4.1/MS4.2**: Prototype technically validated and ready for restricted usability testing (MS4.1) and for human intervention studies (MS4.2) {common MoV: Deployment of prototype for usability testing in KUST and validation use-case tests of D4.4}; **MS5.1/MS5.2**: Care4MyHeart deployed in hospital setting (MS5.1) and in home setting (MS5.2) for training {common MoV: Platform installed and validated in Cleveland Clinic and in patient's home}; **MS6.1/MS6.2/MS6.3**: End of initial (MS6.1), strategic (more targeted) (MS6.2) and exploitation (MS6.3) {common MoV: Assessment of KPI13-KPI16}. **Management of collaborators' interaction:** Productive collaboration will be foreseen via monthly meetings and/or group teleconferences to review project procedures (e.g., technical, development issues, reports on progress updates).

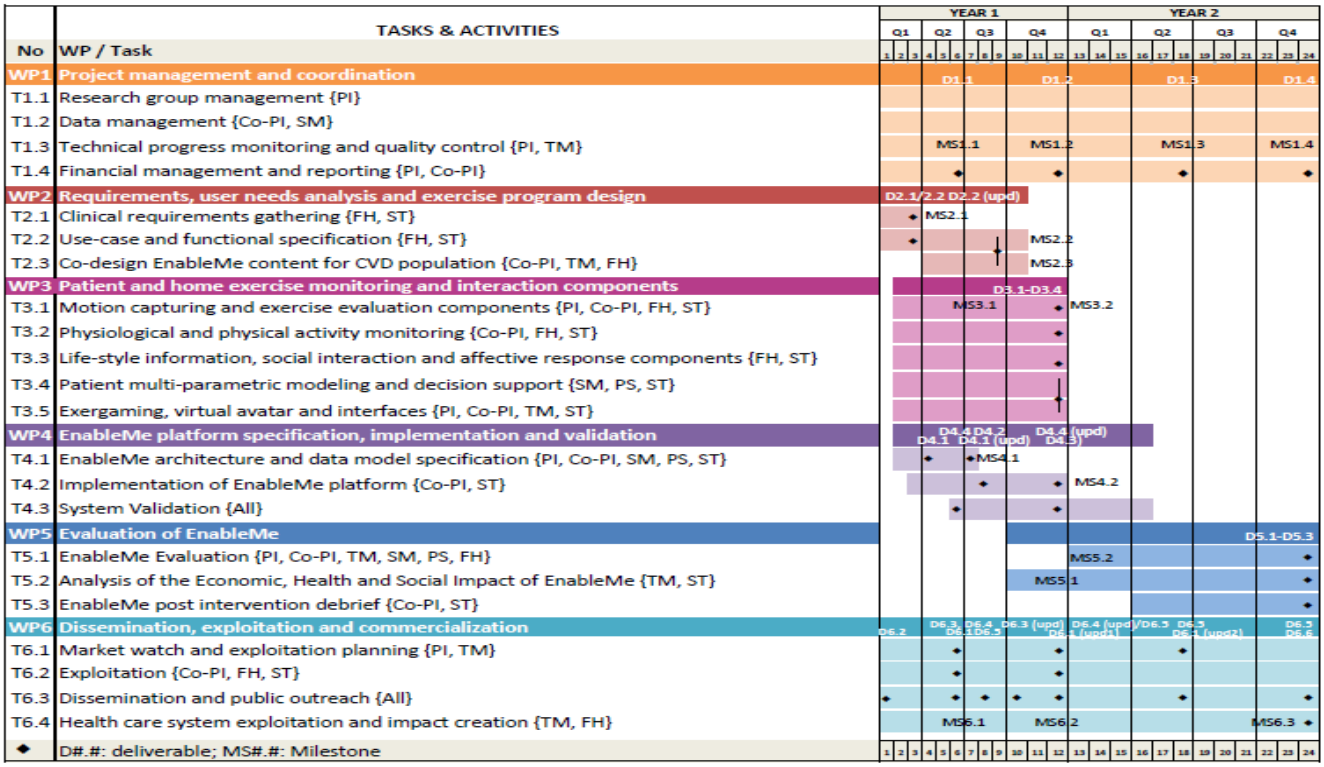

Fig. 4. The **Gant diagram** of the Care4MyHeart project.

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Resources

Khalifa University*:* Khalifa University of Science and Technology Achieves Top University Ranking in the UAE by Times Higher Education University. Electrical and Computer Engineering (ECE) and Biomedical Engineering (BME) Departments housed a number of research and teaching laboratories equipped with modern research facilities to foster research and education in healthcare and signal processing in the UAE. Therefore, well-established laboratories of KUST will provide all the computational power requirements for the big data analysis, training, testing and modeling within the proposed Care4MyHeart project.

Cleveland Clinic: Cleveland Clinic Abu Dhabi is a unique and unparalleled extension of US-based Cleveland Clinic's model of care, specifically designed to address a range of complex and critical care requirements unique to the Abu Dhabi population. Heart & Vascular is one of the five Centers of Excellence of Cleveland Clinic Abu Dhabi. In all, more than 30 medical and surgical specialties are represented at Cleveland Clinic Abu Dhabi. It is a physician-led medical facility served by North American board certified (or equivalent) physicians. The Heart & Vascular Institute brings the experience of the United States' top-ranked heart center to the Middle East, and is one of the five Centers of Excellence at Cleveland Clinic Abu Dhabi. Led by some of the world's most respected physicians and surgeons, it offers basic diagnostic to cutting-edge treatments such as hybrid coronary revascularization, and minimally invasive and robotic cardiac surgery. The Institute was the first in the Middle East to introduce transcatheter aortic valve replacement (TAVR) as an alternative to traditional open-heart valve replacement surgery. Dr Hasan and his collaborators (Dr Johannes Bonatti, Dr Rakesh M. Suri, Dr Murat Tuzcu, and Dr Tomislav Mihaljevic), have extensive experience to deal with the CVD patients and have access to all equipment for cardio-related examinations within the clinical setting.